The Distribution of Volcanic Aerosols in Hawaii from VOGNET

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ABSTRACT

Measurements of condensation nuclei concentration in two size ranges and aerosol optical depth at two wavelengths have been made by VOGNET, a network of high schools located around the island of Hawaii. Between October 1996 and May, 1999 over 6000 measurements were made by students at five locations: Pahala, Kealakekua, Waimea, Hilo, and Pahoa. These data show how the particle concentration, size distribution, and aerosol optical depth varies around the island as a function of the prevailing wind direction and altitude above sea level. An automated condensation nuclei counter built for VOGNET measured the diurnal cycle of particle concentration at these sites.

INTRODUCTION

Kilauea volcano on the Big Island of Hawaii has been in nearly continuous eruption from the Pu'u O'o and Kupaianaha vents on its east rift zone since 1983. During the period of this study, SO_2 emissions from these sites have ranged from less than a few hundred to over 7000 metric tones per day, while emissions from the Kilauea summit have varied from 40 to 240 metric tones per day [1]. The average SO_2 emission rate from Kilauea volcano was greater than that from any EPA-listed anthropogenic source in the United States.

Aerosol particles are produced from volcanic SO_2 ("vog") and by the interaction of molten lava and sea water where lava enters the ocean ("laze"). Vog consists mostly of sulfuric acid and sulfates, while laze contains hydrochloric acid [2]. In normal easterly trade wind conditions, the leeward southern and western sides of the Big Island suffer from reduced visibility, crop damage, and health complaints due to the persistent presence of vog and laze.

VOGNET was organized in September 1996 in a partnership between Mauna Loa Observatory (MLO), a baseline climate monitoring station of the National Oceanic and Atmospheric Administration (NOAA), and teachers from several Big Island public and private high schools. NOAA provided surplus and obsolete instruments, MLO trained volunteer high school teachers to make observations and reduce data, and the teachers supervised students in taking measurements during school hours. The measurements were archived by students at one of the schools (HPA-Hawaii Preparatory Academy), and used in classroom exercises and science fair projects. HPA maintains a VOGNET web page at http://vognet.hpa.edu that gives a description the program and provides public access to the complete database.

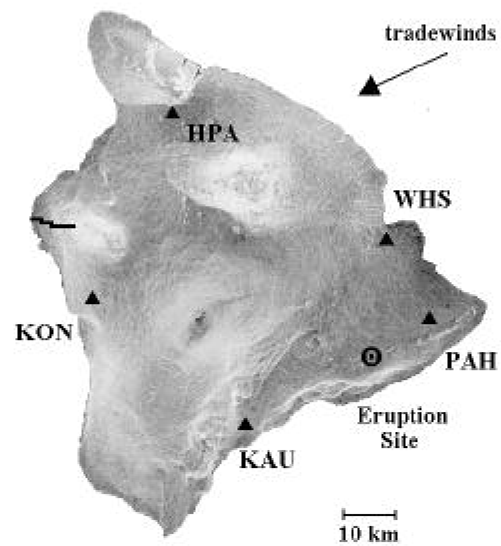

Figure 1. Location of VOGNET sites on Hawaii

METHODS

Daytime measurements were made at Kau High School in Pahala (KAU), Konawaena High School in Kealakekua (KON), Hawaii Preparatory Academy in Waimea (HPA), Waiakea High School in Hilo (WHS), and Pahoa High School in Pahoa (PAH). These sites are shown in Figure 1 along with the location of the Kilauea volcano eruption site.

Aerosol optical depth was calculated from observations using NOAA J-Series handheld sunphotometers with 380nm and 500nm narrow-bandpass interference filters [3]. Calibrations were made at MLO on 9/96, 1/97, 7/97, 11/97 and 11/98 using the Langley method. The instrument response decreased by an average of 18% per year due to degradation of the filters. Observations were reduced using linearly interpolated calibration constants.

Condensation nuclei (CN) were measured with Gardner Counters [4]. In a Gardner Counter, a saturated air sample is subject to a rapid underpressure which causes water vapor to condense on the particles, forming a water droplet fog. The light transmission through the fog is measured and this is converted to particle concentration using a calibration curve for each instrument. The minimum particle size detected by the Gardner Counter can be adjusted by changing the amount of underpressure applied to the air sample. Routine VOGNET measurements were made at the two extreme settings of the instrument, >0.26 microns and >0.002 microns. CN counters experience a loss of counting efficiency for particles smaller than 0.01 microns [5]. All of the VOGNET Gardner Counters were calibrated relative to the MLO CN standard Pollak Counter on two separate occasions by making simultaneous measurements of a smoke aerosol in a 1m^3 box.

In July 1998 a continuous CN counter was built on the operating principle of a Gardner Counter. This continuous counter used standard plumbing hardware, solenoid valves, a laser diode light source, and a personal computer for control and data acquisition. It made one measurement every minute of >0.01 micron particles and was calibrated relative to the MLO Pollak standard. The continuous counter was deployed for 1-3 months at a time at each of the VOGNET schools.

RESULTS

The long-term average CN concentration and aerosol optical depth at the five sites is shown in Figure 2. Optical depth measurements were stopped at several schools after May, 1997 because of frequent cloudiness at windward sites, problems with filter degradation, and data quality concerns.

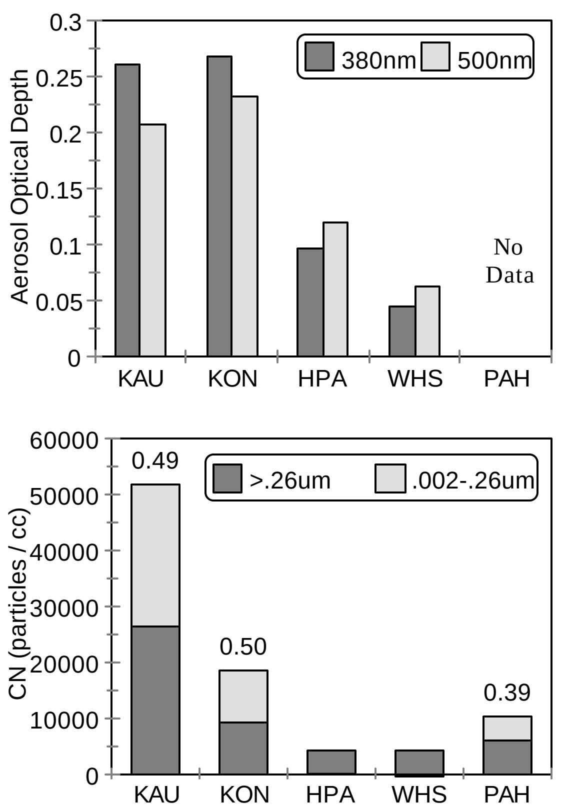

Figure 2. TOP Aerosol optical depth at two wavelengths between October 1996 and February 1997. BOTTOM Condensation nuclei in two size ranges between October 1996 and May 1999, with the fraction of small particles indicated.

The sites in Figure 2 are arranged in clockwise order of their coastal distance from the volcano. The average optical depth was greatest and similar at the leeward sites of KAU and KON then decreased clockwise around the island to a minimum at windward WHS. Average condensation nuclei concentrations were greatest at KAU (30 km downwind of the eruption site), significantly less at leeward KON, and equally low at windward/rural HPA and windward/suburban WHS.

At the downwind sites of KAU and KON, about 50% of the particles were smaller in diameter than 0.26 um, while the windward sites of HPA and WHS had virtually no <0.26 um particles. This feature was also seen in the optical depth measurements. Leeward KAU and KON had a greater average optical depth at 380 nm than at 500 nm, while the inverse was true at windward HPA and WHS. Measurements of particle size distributions using a laser optical particle counter aboard an aircraft by Clarke and Porter [6] have shown that the volcanic plume aerosol is centered around 0.3 um diameter, while the background marine aerosol has a distribution centered around 2-3 um.

PAH is only 15 km upwind of the eruption site and is located near the geothermally active Kilauea east rift zone. The average fraction of <0.26 um diameter particles at PAH was about 40%.

In 1997 students from West Hawaii Explorations Academy made CN measurements at altitudes from sea level to 910 meters along a road between Keahole Point and the top of Kaloko Drive (located on the WNW coast, Figure 1). Twenty five transects were averaged to produce the vertical profiles shown in Figure 3. The aerosol layer at this location has a maximum concentration at an altitude of 500-600 meters, which happens to be about the same as the 520 meter elevation of KON, 15 km to the south. At sea level, the average concentration was near the marine boundary layer background level.

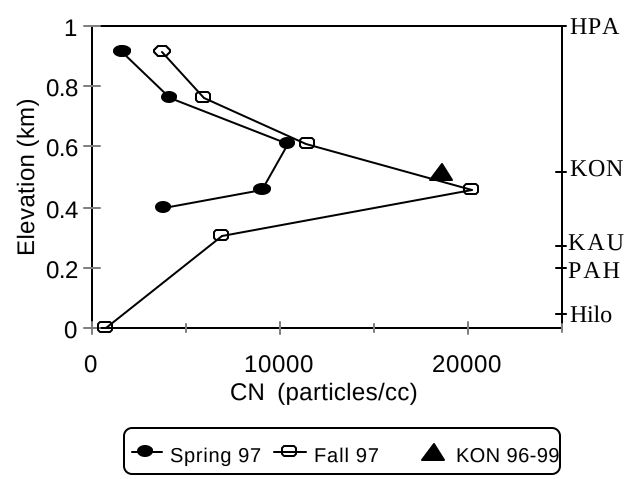

Figure 3. Average condensation nuclei concentration between 11 AM and 1 PM at several elevations along a road on the western slope of Hualalai volcano. Elevations of the VOGNET school sites are shown on the right for comparison.

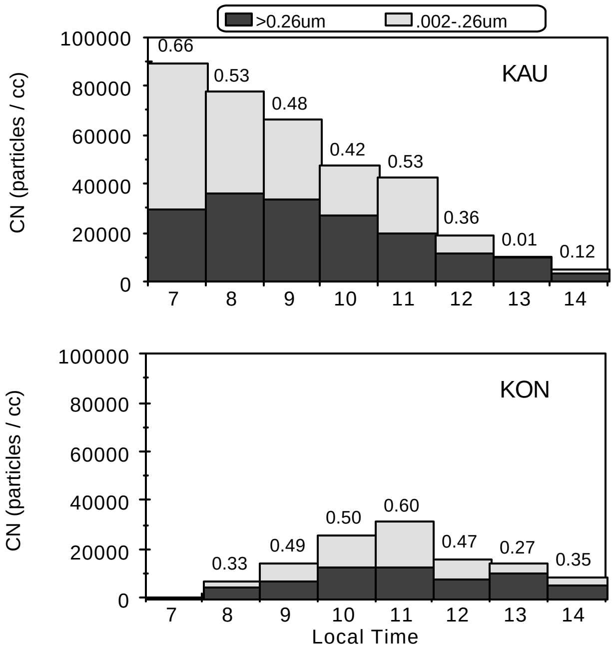

Figure 4. Average particle concentration during the day at KAU and KON between October 1996 and May 1999. The numbers above the bar give the fraction of particles <0.26 um in diameter.

At KAU the fraction of <0.26 um particles remained near 50% throughout the morning, then dropped to near zero by 1 PM (Figure 4). At KON, both the total concentration and fraction of <0.26 um particles were greatest at 11 AM. The average small particle fraction at KON did not drop below about 30% during the day.

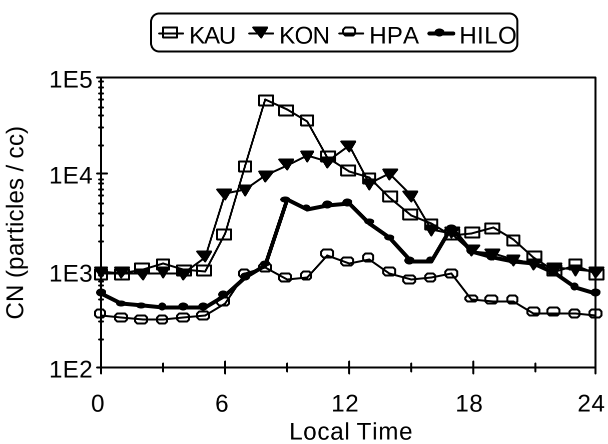

Figure 5. Hourly average concentration of >0.01 um particles at four sites. KAU: 1/29/99-4/9/99, KON: 4/22/99-5/22/99, HPA: 10/3/98-1/4/99, HILO: 5/28/99-6/23/99. The Hilo site was in the Kaumana residential neighborhood.

The automated CN counter was deployed at various sites in 1998-1999 (Figure 5). All sites had minimum particle concentrations between midnight and 5 AM, a period when surface temperature inversions and downslope/land breeze winds are well developed. At windward locations (HPA and suburban Hilo) the average minimum concentration was 300-400 particles per cc, similar to that measured in unpolluted marine air [6]. At leeward sites (KAU and KON) the average minimum was about 1000 particles per cc.

The particle concentration began rising at 6 AM at all four locations. At KON, HPA, and Hilo, maximum particle concentrations occurred just before noon, while at KAU, there was a sharp maximum at 8 AM.

Although the eastern coast generally experiences relatively clean air, westerly or southerly winds can bring high concentrations of volcanic aerosols to these locations. The maximum concentration of >0.002 micron particles measured at each site (with Gardner Counters and the continuous counter) between October 1996 and May 1999, in particles/cc were: KAU 800,000; KON 348,000; HPA 48,000; WHS/Hilo 316,000; PAH 140,000. Higher concentrations at PAH were probably missed because of poor temporal coverage.

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